Taxiway Navigation and Situation Awareness Operational Integration

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The Taxiway Navigation and Situation Awareness (T-NASA) system is a suite of cockpit displays (composed of a head-up display (HUD) and an electronic moving map (EMM) as shown in figure 1) designed in support of the Aero-Space Technology Enterprise research objective to maintain safety while tripling throughput in all weather conditions. The T-NASA taxi HUD uses scene-linked symbology, superimposed on the forward scene, to present taxi route information, situational awareness information, and ground speed. The EMM depicts the cleared taxi route, as well as real-time information about ownship position, airport traffic, and hold-short locations. The T-NASA system assumes that in the future taxi clearances will be data linked, allowing for both a textual and graphical representation in the cockpit, improved taxi route conformance, and improved traffic flow.

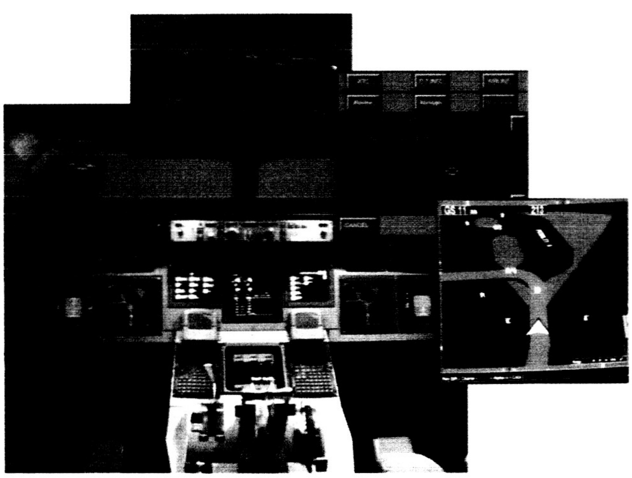

Fig. 1. T-NASA display suite integrated into NASA's Advanced Concept Flight Simulator with insets of the head-up display, data-link display, and electronic moving map.

During FY99, our accomplishments included the development and evaluation of two implementation plans for integrating T-NASA into surface operations. The Transition Implementation, designed to integrate easily into near-term operations, required minimal procedural and equipment modifications. The most notable modification was the introduction of data-link backup to ATC voice communications. The Future Implementation promised greater efficiency benefits, but required revolutionary modifications to current operations such as the sole use of data link for all routine ATC-pilot communications and the introduction of airborne taxi clearances.

A series of focus groups and a high-fidelity simulation conducted in Ames' Advanced Concept Flight Simulator (ACFS) investigated the operational issues associated with the Transition and Future implementations of the T-NASA displays. The simulation focused on issues raised during the focus groups including the timing and format of taxi clearances, pilot workload, situational awareness, and complacency. Commercial airline crews (18) completed 14 low-visibility (runway visual range (RVR) of 1,000 feet) land-and-taxi scenarios that included both nominal taxi events (such as hold-shorts and route amendments) and off-nominal events (such as near traffic incursions, clearance errors, and display information inconsistencies). All crews completed four baseline scenarios using current standard operations and equipment. In addition, crews completed 10 scenarios with either the Transition Implementation (9 crews) or the Future Implementation package (9 crews).

T-NASA increased taxi speeds by 16% (2.2 knots) over present scenarios while simultaneously eliminating major navigation errors (making a wrong turn, failing to turn) which occurred in 20% of the present scenarios. Further, the revolutionary changes embedded in the Future Implementation package produced large efficiency benefits. Specifically, when taxi clearances were data linked to pilots while airborne (outside outermarker), the time spent stopped after runway turnoff was eliminated (saving approximately 10 seconds per trial), and taxi speeds during this typical bottle-necked phase of taxiing increased by approximately 78% (7.4 knots). Also, the Future Implementation package provided substantial improvements in ATC-pilot communication efficiency by reducing radio congestion and communication errors. These results suggest not only that T-NASA can provide substantial benefits in terms of the efficiency and safety of surface operations, but that further gains may be realized by incorporating revolutionary changes to surface operations such as the use of data link and airborne taxi clearances.

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Hybrid Systems

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It is the central tenet of the Free Flight concept that the proper distribution of real-time decision-making between users and air traffic service providers will improve system safety and efficiency. Consequently, it is important to thoroughly understand the trade-off between centralized and decentralized information flow and control for such large systems. Technically such systems are difficult to analyze because they are composed of many objects that interact in a complex and hybrid environment. At present there are no effective analytical tools for use in the design and analysis of such systems. The objective of the present task is to contribute, through university research grants and internal research, to the development of such tools, and to then apply them to the specific case of air traffic management. The participating universities are the University of California at Berkeley, University of Utah, University of Illinois at Chicago, Wayne State University, Case Western Reserve University, and State University of New York at Stony Brook.

One approach that is followed is to try to understand in detail simpler problems and to then generalize the results to the real problem. An example is shown in the figure. The system evolves on a rectangular grid, and only two-dimensional motion along the grid is permitted. There are sources injecting objects representing individual flights into the grid and sinks absorbing the objects. Sources and sinks may represent departure and arrival airports or entry and exit cells at a given flight level. In the figure, the cell at (1,1) is both a sink for gray objects and a source of black objects. Conversely, the cell at (12,14) absorbs black and injected gray objects, respectively. In the example there are only two colors; in the general case there may be many more. Each object attempts to minimize the total number of steps that it takes to move from source to sink. There are many solutions for each object. Safety dictates that occupation of the same cell or the interchange of cells is forbidden. System cost is the conflict-free total deviation from the sum of individual minima. The following questions are addressed: Does a given departure schedule have a zero-cost solution? Does a given pattern on the grid have a zero-cost solution? In either case if there is a solution, can the solution be constructed with only local information and local rules and decisions, or are global information and central control necessary? If there is no zero-cost solution, then what are the minimum-cost solutions? What is the most efficient modification of the schedule or pattern? The key objective of the research is to obtain answers to these questions analytically and only from the properties of schedules and patterns. Progress has been made in this direction, and theorems have been developed that guarantee local cost-free solutions.

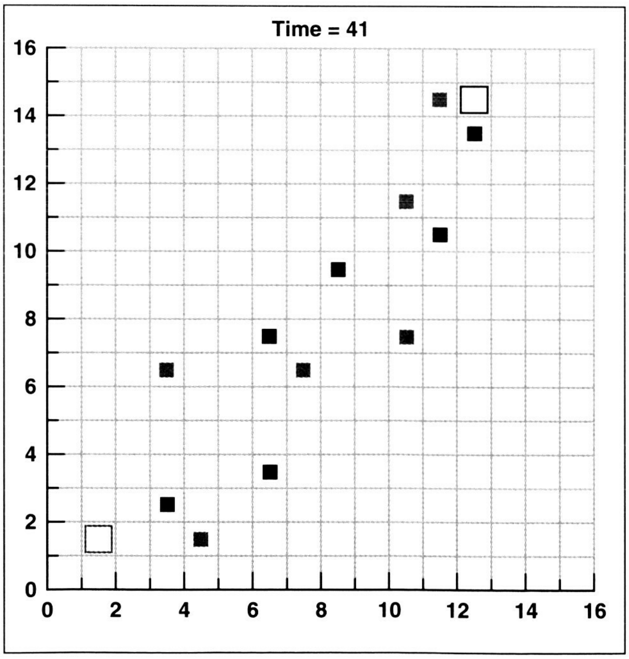

Fig. 1. An example configuration.